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Biomarker and Biometric Indices of Physical Exhaustion in the Firefighting Community

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Abstract

Firefighters are three times more likely to die on the job than any other occupation with half of these deaths due to heart attacks, stroke, or heat exhaustion from stress and over exertion [1]. Most protection of firefighters is focused on gear and equipment. Our objective is to test biomarkers and biometrics of high physical exertion in the laboratory and the field to discover irregular patterns of physiological or biological responses in order to save lives. Twenty firefighters between the ages of 22-57 participated in 5 sessions of testing. Session 1 provided baseline fitness levels with a VO2 Maximal Treadmill test and DEXA body composition scan. Session 2 utilized a Modified Astrand Treadmill protocol with participants wearing full firefighter gear minus the mask. Session 3 was the Firefighter Combat Challenge simulation. Session 4 was a live fire evolution in their training building. Finally, Session 5 repeated session 2 with the addition of a cooling vest worn under the gear. Results showed for biomarker indices of physical exhaustion that lactate and serotonin significantly increased immediately following physical exhaustion while cortisol and DHEAS significantly increased 10 minutes following the exhaustion. Some biophysiological patterns were also found. We also found some biological recovery patterns. Serotonin and orexin-A have opposing trends from post physical exhaustion to 10 minutes post physical exhaustion. Cortisol and DHEAS have opposing trends between the two blood draws as well. These results can help drive the innovation for real-time biosensors to diagnose and analyze physiological and cognitive health for firefighters.

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Keywords: Biomarker; Biometric; Cortisol; Serotonin; Orexin-A; DHEAS; Breath Rate; Physical Exhaustion; Core Body Temperature

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1. Introduction

U.S. Department of Labor statistics indicate that firefighters are three times more likely to die on the job than any other occupation [1]. Improvements in tactics and equipment have reduced the overall number of on-duty deaths. However, the number of annual firefighter deaths in the US remains high. Recently released data indicates that 104 U.S. firefighters lost their lives on duty during 2006 [3] while 115 were lost in 2005 [4]. Of the deaths reported during 2005, more than half (54%) can be attributed to stress or overexertion including heart attacks, cerebrovascular events (stroke) or other types of cardio-respiratory system collapse (heat exhaustion etc.; [5]).

Human protection for the Air Force Fire Fighting community has largely focused on firefighting gear and equipment configurations. The selection of appropriate gear and equipment influence the physiological adaptability of the human, who is ultimately fighting the fire. Smith, Petruzzello, Kramer, Warner, Bone, and Misner [6] examined the physiological impact of the NFPA 1500 standard firefighting gear. They found that mean skin temperature, subjective respiration, and subjective thermal sensations were all reported to be higher for the NFPA 1500 standard fighting gear than for the hip boot and station blues conditions. This was also true for heart rate, oxygen consumption, and rectal temperatures. Fire fighters are not the only groups to experience heat exhaustion due to equipment or carry overload. The Combat Engineer Snapper (Army) carries anywhere from 59-132 extra pounds depending on a fighting or emergency approach load; the M249 SAW Gunner (Army) carries a range of 79-140 pounds depending on a fighting or emergency approach load. Heat stress due to physical exhaustion is a risk for these individuals and this physiological stressor leads to cognitive decrements that include arithmetic [7], short-term memory, long-term memory [7], attention [8], and visual information processing [9]. Thus, there is a need for wearable physiological monitors that can track changes in physiology in real-time that will alert unit commanders when an individual becomes unfit for duty.

State of the art sensors and diagnostic tools are continuously being researched, tested, and procured for every piece of high tech equipment in the Air Force while the most critical asset, the Airman, lacks diagnostics to analyze physiological well-being and cognitive performance. Heat stress, hydration levels, and cognition are largely self-assessed or visually assessed by a fellow Airman without any quantitative metric. The goal of this project is to take the biomarkers and biometrics that are found to be predictive in a laboratory study of cognitive impact due to physical exhaustion and test them on the Fire Fighter population at Wright Patterson Air Force Base using their standard equipment and training regimen.

2. Methods

Twenty firefighters volunteered for this study from Wright-Patterson Air Force Base. All firefighters were male and between the ages of 22-57. The firefighters completed five sessions of data collection. The first session was to complete DEXA scanning and the VO2 Maximal Treadmill exercise. The second session was to complete the modified Astrand Treadmill protocol while they wore their standard firefighting equipment and uniform. Session three was the Firefighting Combat Challenge. Session four was a live fire evolution. Finally, the fifth session repeated session two with the addition of a cooling vest underneath their uniform. This paper will focus on the methods and results from the second session only.

2.1 Session 2 Procedures

This session included a pre, post, and recovery blood draw, the collection of sweat production, a pre and a post cognitive battery, a pre and post capillary blood lactate sample, physiological monitoring, and the modified Astrand Treadmill Protocol. Volunteers came to the laboratory wearing their standard uniform and with their standard firefighting equipment. Upon arrival, the subjectswere asked to be seated in a reclining position and a certified medical technician inserted an IV cannula into the volunteer’s forearm or antecubital vein. A certified medical technician then took a 5ml blood sample. The 3M Tequdeam+Pad sweat patches were then positioned on the forehead, lower left back, and lower right back. Finally the physiological monitoring devices were attached to the volunteer and a two-minute baseline collection was taken. The volunteer was asked to fully “gear-up” with their standard firefighting equipment, with the exception of the mask. Capillary blood lactate was collected and the Astrand Treadmill

Protocol began. Immediately following the protocol test, capillary blood lactate was collected, and a 5ml blood sample was taken. Ten minutes following the treadmill protocol, a recovery blood draw was collected. Then the IV and the sweat patches were removed. Data was collected from the physiological monitoring systems during the Treadmill protocol and for two minutes prior to the recovery blood draw. This Session lasted no longer than 2 hours.

2.1.1 Blood Sampling

The three blood samples were taken during Session 2 collected via a peripheral intravenous (IV) cannula placed on an accessible forearm vein to avoid interference with the treadmill activity by a certified medical technician, using standard antiseptic procedures and BD vacutainer tubes with Red tops. The IV cannula was inserted at the beginning of the Session and remained attached for the duration of testing (120 minutes). The IV was secured with a clear occlusive dressing to avoid distress and discomfort during the treadmill portion of the task. For each sample, 5 ml of blood was collected into a serum separator tube (SST) and allowed to clot for 30 min at room temperature. The tube was centrifuged 10 min at 1000 x g. Serum was removed, separated into 200 µl aliquots, and stored at -80 degrees C. Samples were thawed on ice prior to protein analysis.

2.1.2 Physiological Monitors

Physiological monitoring was achieved with theBioHarness™ (Zephyr), and was used to non-invasively monitor and collect selected physiological data associated with the autonomic nervous system activity. The basic unit consists of a belt that includes imbedded fabric sensors/electrodes for monitoring ECG and calculating heart rate and heart rate variability, respiration rate, and estimated core body temperature.

2.1.3 Modified Astrand Treadmill Protocol

A modified Astrand Treadmill Running Protocol [10]was administered. The data collected from this firefighter population was compared to the data collected from the active duty volunteers from the previous study. Subjects start at a slow running speed of 3.2mph with a 0% grade for 3 minutes. There were 24 stages and each stage lasted 2-3 minutes. Speeds stay constant as the incline increased to a grade that will range between 2% incline and 16% incline. Subjective affect and perceived ratings of exertion were assessed at each 2% incline period. Responses to the subjective affect items and the perceived exertion items were verbal and recorded by a research associate. The last stage prior to post-testing included a gradual increase until each participant has reach 80% of their maximal heart rate, which was identified during the VO2 max testing that took place during the first session. For further details refer to Shia, Traver, McIntire, Hagen, Goodyear, Dykstra, and Myers [11].

3. Results

Twenty firefighters completed Session 2 of this study. Pre, post, and post 10 minutes during the treadmill exercise, biomarker and biometric variables were recorded. The purpose of this analysis was to determine significant changes from pre to post exercise as well as post 10-minutes exercise and to correlate values at each time point for all variables. These results are also compared with the results of our previous study using active-duty AF personnel. All comparisons used an alpha of .05, with no familywise error level adjustments.

Table 1 shows the baseline biomarker comparisons between the active-duty AF personnel and the firefighters. The firefighters had significantly lower levels of DHEAS and DHEAS/Cortisol rations. Firefighters also had significantly higher baseline levels of Orexin and Serotonin.

Table 1. Baseline Biomarker Comparison

	Active-Duty		Firefighter		Mean	Two-Tailed Two-Sample t-test		
Dependent Variable	Mean	SEM	Mean	SEM	Diff	DF	t	p
Cortisol (ng/mL)	315.8	21.6	336.3	23.0	-20.5	32	-0.64	0.5286
DHEAS (ng/mL)	3501	186	2061	173	1440	32	5.63	0.0001
Log of DHEAS/Cortisol	2.414	0.067	1.795	0.097	0.619	32	4.98	0.0001
Log of Orexin	6.028	0.233	6.657	0.159	-0.629	33	-2.29	0.0283
Log of Serotonin	4.880	0.137	5.796	0.119	-0.915	33	-5.07	0.0001

The bar charts in Figure 1 compare the biomarker levels of both groups throughout the treadmill exercise. Figure 1 shows the mean (-SEM) for pre, post and post 10 minute treadmill exercise and results of the change from pre to post or post 10 minute using two-tailed paired t-tests. Note there were no significant differences for any variable from post to post 10 minute. The * denotes significantly different from pre ($p \leq 0.05$). The active-duty AF members completed the same treadmill protocol while wearing a 50lb weighted vest. The trends found are the same for both groups. It should be noted that DHEAS/Cortisol ratios are not meant to change for the group as a whole. It is an individual difference factor where some people will increase while others will decrease. There was a significant change in Cortisol from pre to post 10-minute treadmill for the firefighters [t(19) = 2.31, p = .033] and the active-duty[t(13) = -2.54, p = .025]. A significant change from pre to post 10-minute was also found for DHEAS in the firefighter [t(20) = 2.41, p = .026] and active-duty groups[t(13) = -2.48, p = .028]. There was also a significant change found for Serotonin pre to post treadmill exercise for firefighters [t(20) = 4.09, p = .001] and active-duty [t(16) = -3.68, p = 002].

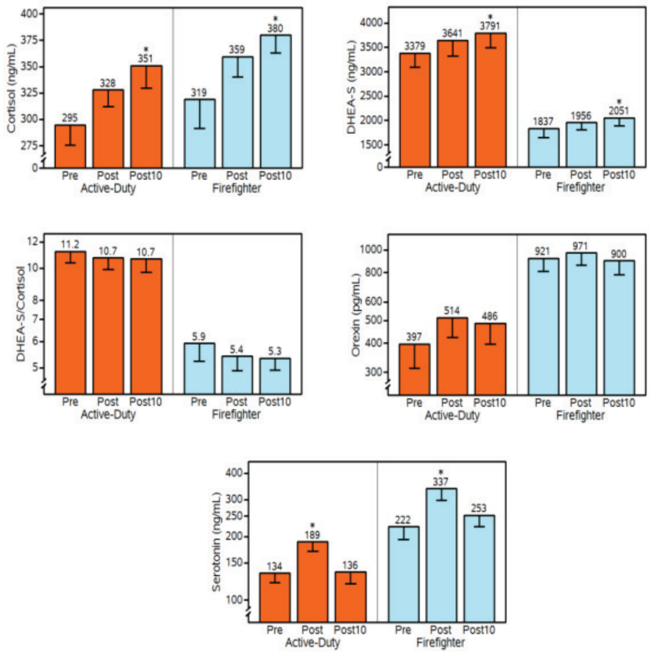

Figure 1.Comparison of Biomarker Levels for Both Groups during Treadmill Exercise

Figure 2 shows the physiological trends for both groups. The numbers at the bottom of the x-axis indicate minutes while the numbers at the top of the x-axis indicate the incline of the treadmill.

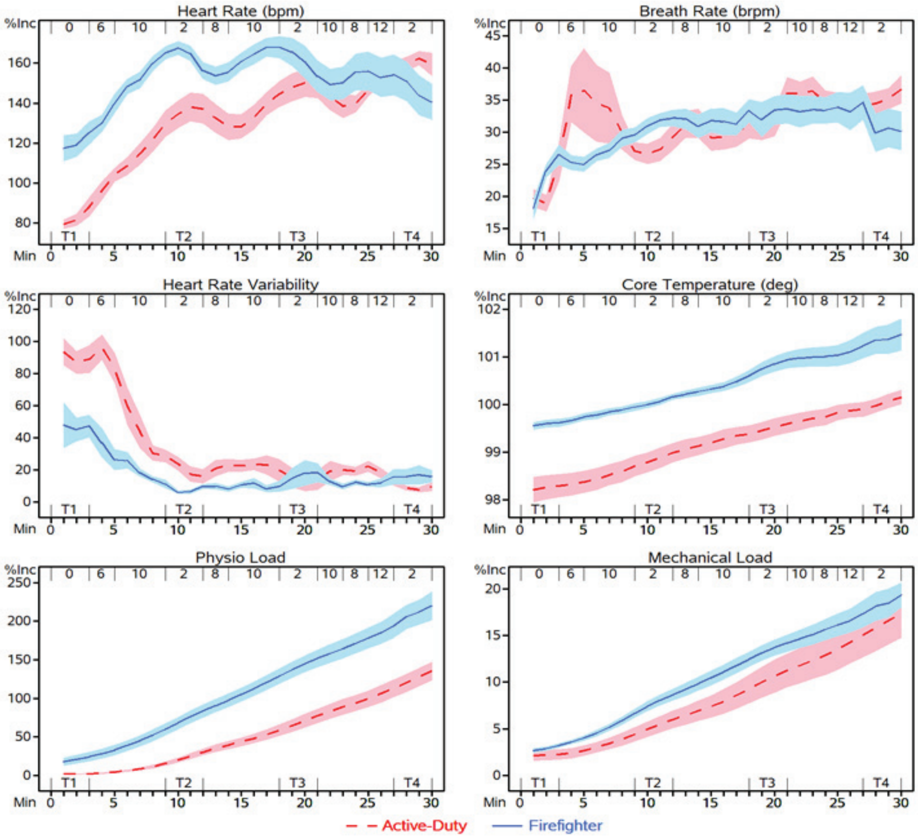

Figure 2.Biometric Trends for Active-Duty AF and Firefighters

Figure 3 encompasses the correlations between Cortisol post treadmill exercise and various biometrics. The results show that Cortisol post is related to mechanical load, physiological load, breath rate, core body temperature, and core body temperature rate of recovery. Mechanical load is based on the rate of accelerometry as measured by the Zephyr.Physiological load is also measure by the Zephyr and is based on heart rate. Cortisol and the biometrics all have a positive relationship except for core body temperature rate of recovery.

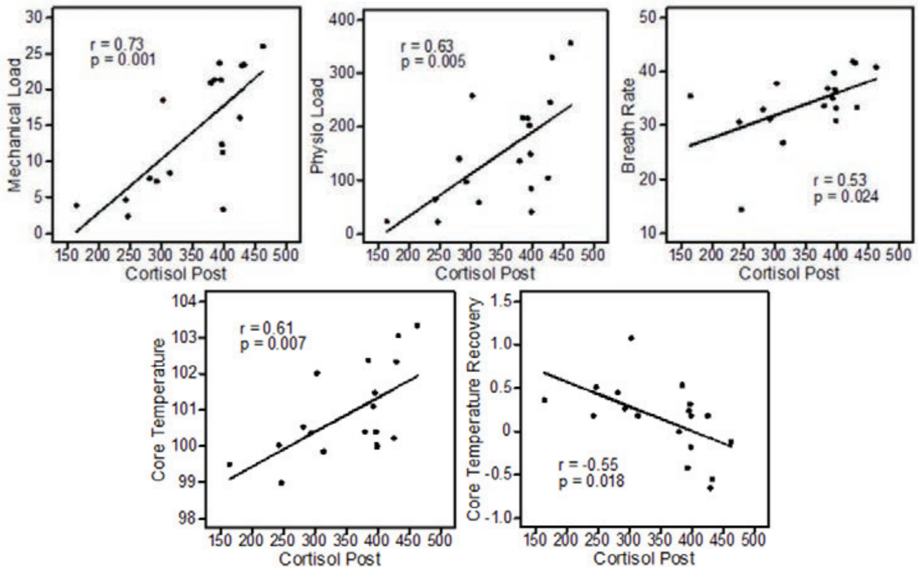

Figure 3. Cortisol Post Treadmill Exercise Correlated with Biometrics

Figure 4 illustrates the significant correlations between lactate changes from pre to post treadmill exercise in relation to core body temperature and core body temperature rate of recovery. The higher the lactate then the higher the core body temperature.

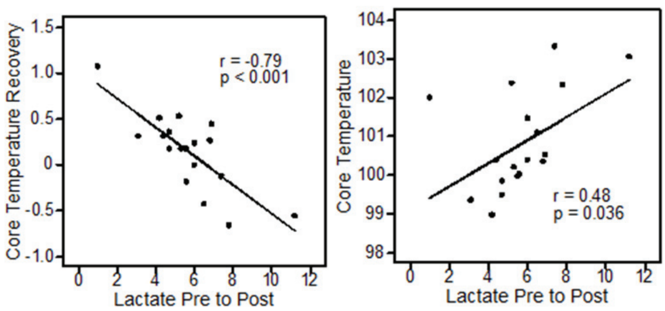

Figure 4. Lactate Pre to Post Treadmill Exercise Correlated with Biometrics

4. Discussion

The purpose of this study was to not only understand the general health and stress levels of firefighters both on and off-duty but to also compare that to a previously run study with active-duty Air Force men. The results of the baseline biomarker levels showed that compared to the AF personnel, the firefighters had significantly lower DHEAS levels and DHEAS/Cortisol ratios. Low DHEAS/Cortisol rations have been found to be related to anxiety and chronic stress [12]. Firefighters also had significantly higher levels of Orexin and Serotonin at baseline. Orexin-A is related to both appetite and sleep regulation [13] and thought to be related to alertness [14] while Serotonin is known for the regulation of mood, digestion, and vascular contraction and relaxation [15]. This means that firefighters most likely have higher chronic stress, anxiety, poor appetite and digestion, poor sleep, and decreased mood when compared to active-duty Air Force personnel. These findings alone help explain why not only firefighters are more likely to die on the job than any other occupation [1] but also why over half of those deaths are attributed to stress and overexertion instead of an actual fire related injury [5].

Biomarker levels for each blood draw during the treadmill exercise showed that Cortisol and DHEAS significantly increase 10-minutes post-exercise. Serotonin also significantly increase immediately post exercise but returned to baseline by the 10-minute post exercise blood draw. These results are the same trends found for the active-duty AF personnel. Cortisol and DHEAS are neurohormones and are expected to show a delay in production following stress. These biomarkers are related to chronic stress and are better indicators of long term stress exposure. Occupations of high stress should monitor these biomarkers as low DHEAS:cortisol can signal the development of anxiety disorders [12]. In fact, one finding not discussed in this paper was that Firefighters who reported greater chronic stress also exhibited lower DHEAS:cortisol ratios post stress during the simulated Firefighter combat challenge.

Several biometric trends were found to be significantly correlated with Cortisol post treadmill exercise. One of those metrics was mechanical load which, is based on the rate of accelerometry as measured by the Zephyr harness. The results showed that the amount of activity put out by the participant was related to higher levels of Cortisol post exercise. Specifically, the harder a participant worked then the higher their level of Cortisol post treadmill exercise. This same positive relationship was also found with breath rate, core body temperature, and physiological load. Physiological load is also metric on the Zephyr harness that is based on changes in heart rate during the exercise. Therefore, as the physiological load (heart rate) increased so did the Cortisol levels. Changes in cortisol were related to changes in core body temperature. The higher the Cortisol levels the higher the estimated core body temperature and the longer the rate of recovery for the core body temperature estimate. Quick and high spikes in cortisol during stress, along with a group of catecholamines such as adrenaline, noradrenaline, and dopamine coupled with rapid declines back to baseline levels is characteristic of physiological toughness or stress resilience [2].Lactate was also found to be related to core body temperature and the rate of recover of the estimated core body temperature. These relationships are similar to the one found for Cortisol.

In conclusion, the results of this study show that it is critical that biomarker levels are monitored for high stress occupations. Further research should be conducted to determine performance augmentation possibilities from altering stress biomarkers, such as DHEA. In addition, other biomarkers of resilience should be assessed, such as Neuropeptide-Y (NPY). NPY functions by increasing with Norepinephrine to sustain higher order cognitive skills under threat [16]. Deficits in NPY have been known to relate to increases in anxiety and distress [17].

References

[1] C. Clark, M.J. Zak, Office of Safety, Health and Working Conditions, Bureau of Labor Statistics, Washington DC, 1992-1997.
[2] R.A. Dienstbier. Psychol Rev. 96 (1989) 84-100.
[3] U.S. Fire Administration, Emmitsburg, MD, 2007.
[4] U.S. Fire Administration, Emmitsburg, MD, 2006.
[5] J. Brown, J. Strickford. Psychological Stress Associated with Structual Firefighting Observed in Professional Firefighters. Indiana University-Bloomington, School of Health, Physical Education & Recreation, Department of Kinesiology, 2009.
[6] D.L. Smith, S.J. Petruzello, J.M. Kramer, S.E. Warner, B.G. Bone, J.E. Misner. Ergonomics. 38 (10) 2065-2077.
[7] C. Cian, N. Koulmann, P. Barraud, C. Raphel, C. Jimenez, B. Melin. J. Psychophys. 14 (2000) 29-36.
[8] P.M. Gopinathan, G. Pichan, V.M. Sharma. Arch Environ Health. 45 (1988) 15-17.
[9] S.S. Radakovic, J. Maric, M. Surbatovic, S. Radjen, E. Stefanova, N. Stankovic. Military Med. 172 (2007) 133-136.
[10] M.L. Pollock, J.H. Wilmore, S.M. Fox III. Health and Fitness through Physical Activity. New York: John Wiley & Sons, Inc. 1978.
[11] R.M. Shia, K. Traver, L.K. McIntire, J.A. Hagen, C.D. Goodyear, L.N. Dykstra, A.R. Myers. Proc Human Comp Interaction Intnatl. 2014.
[12] M. Boudarene, J.J. Legross, M. Timsit-Berthier, Encephale, 28, (2002) 139-146.
[13] R. Spinazzi, P. G. Andreis, G.P. Rossi, G.G. Nussdorfer. Parmacol Rev. 58 (2006) 46-57.
[14] C. Alexandre, M.L. Andermann, T.E. Scammell, Current Opinion in Neurobiology, 23,(2013) 752-759.
[15] R. Meeusen, P. Watson, H. Hasegawa, B. Roelands, M.F. Piacentini. Sports Medicine, *36*(2006) 881-909.
[16] J.A. McNeil, C.A. Morgan III. In Military Neuropsychology (Eds. C.H. Kennedy, J.L. Moore), (2010). Springer Publisher.
[17] C.A. Morgan III, S. Wang, A. Rasmusson, G. Hazlett, G. Anderson, D. S. Charney. Psychosomatic Med. 63 (2001) 412-422.